Research Report

Joint Range of Motion in Flaccid Hemiplegia

Vimonwan Hiengkaew, PhD; **Pinit Vittayasoontorn**, BSc (Physiotherapy);
Pongporn Meenathanin, BSc (Physiotherapy); **Anchalee Kaewtong**, BSc (Physiotherapy)

Abstract: The effect of muscle tone on passive range of motion (PROM) in affected joints and comparison joints on the unaffected side was investigated in 15 patients with flaccid paralysis hemiplegia. PROM was measured in the shoulder and hip in flexion, extension, abduction, adduction and internal and external rotation using the plastic universal goniometer. PROM in the elbow and knee was assessed in flexion and extension. Wrist PROM was measured in flexion, extension and radial and ulnar deviation. Additionally, ankle dorsiflexion, plantarflexion, eversion and inversion PROM were assessed. Decreased muscle tone significantly affected shoulder ($p = 0.006$), wrist ($p = 0.032$) and hip ($p = 0.003$) PROM. Significant differences between the affected and unaffected sides were found in shoulder PROM in extension ($p = 0.014$), adduction ($p = 0.001$) and internal ($p = 0.034$) and external rotation ($p = 0.007$). Wrist PROM was significantly different in flexion ($p = 0.048$) and extension ($p = 0.001$), and hip PROM was significantly different in abduction ($p = 0.029$), adduction ($p = 0.012$) and external rotation ($p = 0.001$). Surprisingly, although muscle tone had no influence on ankle PROM, there was a significant difference in ankle plantarflexion PROM ($p = 0.013$). In conclusion, in flaccid hemiplegia, decreased muscle tone affects the PROM in the shoulder, wrist and hip. Differences in PROM between the unaffected and affected side are evident in shoulder extension, adduction and internal and external rotation, wrist flexion and extension, hip abduction, adduction and external rotation, and ankle plantarflexion.

Key words: joint range of motion, muscle tone, upper extremity, lower extremity, hemiplegia

Introduction

Muscle tone is a physiological characteristic representing the resting level of tension in a muscle that prepares the muscle for a rapid and reliable response to voluntary or reflexive commands [1]. The tone is automatically generated by the impulse activity of the Ia afferents naturally exciting alpha motoneurons [1]. It is controlled by four neural structures. First, neurons are in the ventral horn of the spinal cord grey matter [1, 2]. Second, neurons have cell bodies that lie in the brainstem and cerebral cortex and extend into the corticospinal tract [1–3]. Third, the cerebellum exerts its control via the spinocerebellar tract [1–3]. And last, the basal ganglia regulate the activities of the brainstem and cerebral cortex [1, 2, 4]. Damage to interneurons, alpha motoneurons and descending pathways causes changes in muscle tone [1].

When muscle tone is decreased, joint stability is lost and joint range of motion increases. Most flaccid hemiplegic patients show shoulder subluxation [5–10]. Glenohumeral joint subluxation occurs when shoulder joint and shoulder girdle stability are lost [11, 12]. In addition, stroke patients with shoulder subluxation have decreased shoulder external rotation range of motion from the evaluation at stroke onset to that 6 months after the stroke [13]. Likewise, in paraplegic patients with flaccid paralysis, hip dislocation easily happens in passive hip adduction and extension [14, 15].

Muscle tone seems to influence joint range of motion and stability [13–15]. In addition, it has been assumed in the clinic, without any evidence, that flaccid hemiplegic

Faculty of Physical Therapy and Applied Movement Science Project, Mahidol University, Bangkok, Thailand.
Received: 24 March 2003. Accepted: 4 August 2003.
Reprint requests and correspondence to: Dr. Vimonwan Hiengkaew, Faculty of Physical Therapy and Applied Movement Science Project, Mahidol University, Siriraj Hospital, Prannok Road, Srisangwann Building, Level 6, Bangkoknoi, Bangkok 10700, Thailand.
E-mail: sivce@mahidol.ac.th

patients have increased range of motion in the affected side. The present study tested the hypothesis that decreased muscle tone causes a significant difference in joint motion range compared to normal muscle tone. The purpose of this study was to determine the effect of muscle tone on joint range of motion, and to compare each direction of joint range of motion on the unaffected side with that of the affected side in flaccid hemiplegia.

Materials and Methods

Subjects

First acute stroke patients who consulted for physiotherapy participated in the study. Subjects had good consciousness, a stable cardiovascular system, flaccid muscle tone, were unable to move, and had never had any passive movement on the affected upper and lower extremities. In addition, they had never had any upper and lower limb surgery. In the affected upper and lower extremities, muscle tone was graded 0 according to the modified Ashward Scale [16], and deep tendon reflexes were graded 0 or 1+ [17]. In the unaffected upper and lower extremities, muscle tone was normal and deep tendon reflexes were graded 2+. Subjects gave written consent after they were informed about the nature of the study and what would be done.

Methods

The muscle tone of all muscle groups in the upper and lower limbs of the unaffected and affected sides was examined by passive manual stretch. Muscle tone was assessed and deep tendon reflexes in the pectoralis major, biceps brachii, triceps brachii, brachioradialis, quadriceps femoris and gastrosoleus muscles were examined.

The following subject characteristics were recorded: age, gender, handedness, brain lesions, affected limb side, date of stroke onset, and date when passive range of motion (PROM) was measured.

The PROM in both the unaffected and affected shoulder, elbow, wrist, hip, knee and ankle joints was measured by only one examiner throughout the study, using the plastic universal goniometer (Sammons Preston Rolyan, Mississauga, ON, Canada). Shoulder PROM was measured in six directional movements: flexion, extension, abduction, adduction, internal rotation and external rotation. Elbow PROM was measured in two directions: flexion and extension. PROM in four movement directions in the wrist joint were measured: flexion, extension, radial deviation and ulnar deviation. Hip PROM was measured in six movement directions: flexion, extension, abduction, adduction, internal rotation and external rotation. Knee PROM was measured in two directions: flexion and extension. Ankle PROM was measured in four directional movements: dorsiflexion, plantarflexion, eversion, and inversion. The subject positions for each direction of PROM measurement as well as the alignment of the goniometer are shown in Table 1. Subjects were given full support in each position and instructed to relax during PROM measurement.

To obtain PROM in each direction of joint motion, each joint was moved in the full range of that motion. At the same time, another examiner measured the range of motion according to standardized measurements [18]. Throughout the study, the examiner who moved each joint was the only one who did the joint movement, and the examiner who measured the range of motion was the only one who performed the measurement. To avoid frequent positional change, PROM was first measured with patients supine and then lying on their side, for both the unaffected and affected sides. In both positions, PROM was assessed in the upper extremity joints before the lower limb joints.

Statistical analysis

The influence of muscle tone on PROM in the shoulder, elbow, wrist, hip, knee and ankle was determined using multivariate analysis of variance (MANOVA). In addition, the influence of muscle tone on PROM in shoulder flexion, extension, abduction, adduction and internal and external rotation, elbow flexion and extension, and wrist flexion, extension and radial and ulnar deviation was determined for the unaffected and affected sides. The influence of muscle tone on PROM at hip flexion, extension, abduction, adduction and internal and external rotation, knee flexion and extension, ankle dorsiflexion, plantarflexion, eversion and inversion was also determined for the unaffected and affected sides. A p value of less than 0.05 indicated a significant influence of muscle tone on PROM in the joints and a significant difference in each direction of joint PROM between the unaffected and affected sides.

Results

Subject characteristics

Fifteen flaccid hemiplegia patients (6 females, 9 males) aged between 24 and 88 years (mean ± SD, 62.8 ± 18.3 years) were included in the study. Four were younger than 60 years (24, 30, 46 and 52 years). Six subjects had deep tendon reflexes of 0 and nine subjects of 1+. Strokes had occurred between 3 and 16 days (8.3 ± 3.7 days) before PROM measurement. One subject was left-handed whilst the others were right-handed. Nine subjects had a right brain lesion; eight were affected on the limbs opposite to the dominant side while only one was affected on the dominant side. Six subjects had a left brain lesion, all of whom were affected in the dominant limbs.

Table 1. Subject position and alignment of the universal goniometer to measure passive range of motion in each directional joint movement in upper and lower extremities

	Directional movement	Subject position	Alignment of goniometer		
			Stationary arm	Moving arm	Axis
Upper extremity					
Shoulder	Flexion/ extension	Side lying, full elbow extension, forearm in neutral with palm facing trunk	Lateral midline of thorax	Lateral midline of humerus toward lateral humeral epicondyle	Lateral aspect of acromion process
	Abduction/ adduction	Supine, arm at side, upper limb in anatomical position	Parallel to sternum	Anterior midline of humerus toward medial humeral epicondyle	Anterior aspect of acromion process
	Internal/external rotation	Supine, shoulder abduction 90°, elbow flexion 90°, forearm pronation	Perpendicular to floor	Ulnar border of forearm toward ulnar styloid process	Olecranon process of ulnar
Elbow	Flexion/ extension	Side lying, arm and forearm in anatomical position	Lateral midline of humerus toward acromion process	Lateral midline of radius toward radial styloid process	Lateral epicondyle of humerus
Wrist	Flexion/ extension	Supine, arm at side, elbow flexion 90°, forearm in neutral rotation	Dorsal (wrist flexion)/volar (wrist extension) midline of fore-arm toward bicipital tendon at elbow	Dorsal (wrist flexion)/volar (wrist extension) midline of 3rd metacarpal	Lunate
	Ulnar/radial deviation	Supine, arm at side, elbow flexion 90°, forearm in neutral rotation	Dorsal midline of forearm toward lateral epicondyle of humerus	Dorsal midline of 3rd metacarpal	Capitate
Lower extremity					
Hip	Flexion	Supine, lower limbs in ana-tomical position	Lateral midline of pelvis and trunk	Lateral midline of femur toward lateral femoral epicondyle	Greater trochanter of femur
	Extension	Side lying, lower limbs in ana-tomical position	Lateral midline of pelvis and trunk	Lateral midline of femur toward lateral femoral epicondyle	Greater trochanter of femur
	Abduction	Supine, lower limbs in ana-tomical position	Toward contralateral anterior superior iliac spines	Anterior midline of ipsilateral femur	Ipsilateral anterior superior iliac spines

Table 1. Subject position and alignment of the universal goniometer to measure passive range of motion in each directional joint movement in upper and lower extremities

	Directional movement	Subject position	Alignment of goniometer		
			Stationary arm	Moving arm	Axis
Hip	Adduction	Same as hip abduction, contralateral hip abduction	Toward contralateral anterior superior iliac spines	Anterior midline of ipsilateral femur	Ipsilateral anterior superior iliac spines
	Internal/external rotation	Supine, hip and knee flexion 90°	Parallel to anterior midline of trunk	Anterior midline of tibia	Midpoint of patella
Knee	Flexion/ extension	Side lying, lower limbs in anatomical position	Lateral midline of femur toward greater trochanter	Lateral midline of fibula	Lateral condyle of femur
Ankle	Dorsiflexion/ plantarflexion	Supine, hip and knee flexion 90°, ankle in anatomical position	Lateral midline of fibula	Lateral midline of 5^{th} metatarsal	Intersection of line lateral midline of fibula and lateral midline of 5^{th} metatarsal
	Inversion/ eversion	Supine, hip and knee flexion 90°, ankle in anatomical position	Anterior midline of tibia	Anterior midline of 2^{nd} metatarsal	Midway between medial and lateral malleoli

Shoulder joint

Muscle tone significantly influenced PROM in the shoulder (p = 0.006). There was no difference in PROM between the unaffected and affected shoulder in flexion (158.1° vs 161.6°; p = 0.415) and abduction (163.4° vs 168.8°; p = 0.262) (Table 2). However, mean PROM in shoulder extension on the affected side (67.7°) was significantly greater than that on the unaffected side (55.5°; p = 0.014). In addition, mean PROM on the affected side (33.3°) was significantly greater than that on the unaffected side (24.0°; p = 0.001). There was a significant difference in internal rotation PROM in the affected shoulder (96.3°) compared to the unaffected shoulder (85.1°; p = 0.034). Moreover, mean PROM in external rotation in the affected shoulder (97.3°) was significantly greater than that in the unaffected shoulder (82.8°; p = 0.007).

Elbow joint

At the elbow joint, muscle tone had no significant effect on PROM (p = 0.869). There was no difference in PROM between the sound and affected sides in elbow flexion (unaffected side, 143.7 ± 6.6° vs affected side, 144.9 ± 7.4°; p = 0.643) and extension (unaffected side, 1.2 ± 3.5° vs affected side, 1.6 ± 3.1°; p = 0.744).

Wrist joint

Muscle tone had a significant effect on wrist PROM (p = 0.032). Wrist flexion PROM was significantly greater in the affected wrist (82.7°) than in the unaffected wrist (75.9°; p = 0.048) (Table 3). In addition, wrist extension PROM in the affected limb (89.3°) was significantly greater than that on the unaffected side (79.4°; p = 0.001). There was no significant difference in wrist radial deviation PROM between the unaffected (19.9°) and affected sides (22.9°; p = 0.346). Similarly, there was no significant difference in ulnar deviation PROM between the unaffected (31.5°) and affected wrists (33.3°; p = 0.557).

Hip joint

Muscle tone had significant influence on hip PROM (p = 0.003). There was a significant difference in hip abduction PROM between the affected (45.6°) and unaffected sides

Table 2. Passive range of motion (PROM) in the shoulder and hip (mean ± standard deviation) on the unaffected and affected sides

Joint movement	PROM		p
	Unaffected side	Affected side	
Shoulder joint			
Flexion	158.1 ± 12.2°	161.6 ± 10.7°	0.415
Extension	55.5 ± 11.9°	67.7 ± 13.7° *	0.014
Abduction	163.4 ± 14.7°	168.8 ± 10.8°	0.262
Adduction	24.0 ± 7.1°	33.3 ± 7.2° †	0.001
Internal rotation	85.1 ± 12.3°	96.3 ± 15.3° *	0.034
External rotation	82.8 ± 11.5°	97.3 ± 15.7° †	0.007
Hip joint			
Flexion	122.5 ± 16.1°	126.4 ± 22.3°	0.584
Extension	16.5 ± 9.3°	18.8 ± 9.9°	0.524
Abduction	37.3 ± 9.8°	45.6 ± 9.8° *	0.029
Adduction	22.3 ± 5.9°	29.4 ± 8.3° *	0.012
Internal rotation	23.3 ± 8.4°	28.5 ± 6.3°	0.063
External rotation	43.9 ± 6.4°	58.3 ± 12.1° †	0.001

*$p < 0.05$, †$p < 0.01$ vs unaffected side.

(37.3°; $p = 0.029$) (Table 2). Additionally, the adduction PROM in the affected hip (29.4°) was significantly greater than that in the unaffected hip (22.3°; $p = 0.012$). Hip external rotation PROM on the affected side (58.3°) was significantly greater than that on the unaffected side (43.9°; $p = 0.001$). No difference in PROM was observed between the unaffected and affected hip in flexion (122.5° vs 126.4°; $p = 0.584$) or extension (16.5° vs 18.8°; $p = 0.524$). Similarly, there was no significant difference in hip internal rotation PROM between the unaffected (23.3°) and affected side (28.5°; $p = 0.063$).

Knee joint

Muscle tone had no significant influence on any knee PROM ($p = 0.947$). There was no significant difference in knee flexion PROM between the unaffected (144.6 ± 8.8°) and affected sides (145.7 ± 10.1°; $p = 0.760$). Similarly, no significant difference was found in knee extension PROM between the unaffected (0.3 ± 1.3°) and affected sides (0.5 ± 1.8°; $p = 0.818$).

Ankle joint

There was no significant influence of muscle tone on ankle PROM ($p = 0.0780$). Ankle dorsiflexion PROM in the sound ankle (19.9°) was similar to that in the affected ankle (21.0°; $p = 0.763$) (Table 3). In addition, no difference in PROM was observed between the unaffected and affected ankle in eversion (7.7° vs 9.5°; $p = 0.407$) or inversion (6.1° vs 6.7°; $p = 0.627$). However, there was a significant difference in ankle plantarflexion PROM between the affected (54.9°) and unaffected sides (43.7°; $p = 0.013$).

Discussion

One goal of physiotherapy during the acute stage of stroke is to maintain range of motion [19]. It has been clinically surmised that there is an increase in PROM in the flaccid muscle, particularly in flaccid hemiplegic patients. To our knowledge, this study is the first to report quantitative PROM data in flaccid hemiplegia. Additionally, the present study provides data that demonstrate significant differences in PROM in each direction of joint motion between the unaffected and affected limbs, which indicates that clinicians need to be careful in excessive PROM exercise in certain joints and directions in flaccid paralysis patients. The results revealed that in acute stroke patients with decreased muscle tone, there were differences in PROM in the shoulder, wrist and hip but not the elbow and knee. Surprisingly, the decreased muscle tone did not significantly affect the ankle joint, although the plantarflexion PROM in the affected ankle was significantly different from that in the unaffected ankle.

In the shoulder, PROM was significantly different between affected and unaffected sides in extension, adduction, internal rotation, and external rotation, but not in flexion and abduction. Rotator cuff muscles consisting of supraspinatus, infraspinatus, subscapularis and teres minor muscles play a role in the stability of the glenohumeral joint. These muscles are the abductors and internal and external rotators of the humerus [20, 21]. In flaccid hemiplegia patients, they lose usual activity and thus cause the shoulder to lose stability [20, 22]. This may result in increased shoulder range of motion in

Table 3. Joint passive range of motion (PROM) in the wrist and ankle (mean ± standard deviation) on the unaffected and affected sides

Joint movement	PROM		p
	Unaffected side	Affected side	
Wrist joint			
Flexion	75.9 ± 7.5°	82.7 ± 10.3° *	0.048
Extension	79.4 ± 7.7°	89.3 ± 6.8° †	0.001
Radial deviation	19.9 ± 8.3°	22.9 ± 8.4°	0.346
Ulnar deviation	31.5 ± 7.1°	33.3 ± 9.3°	0.557
Ankle joint			
Dorsiflexion	19.9 ± 8.4°	21.0 ± 8.8°	0.763
Plantarflexion	43.7 ± 12.2°	54.9 ± 10.8° *	0.013
Eversion	7.7 ± 5.1°	9.5 ± 6.5°	0.407
Inversion	6.1 ± 3.7°	6.7 ± 3.0°	0.627

$^*p < 0.05$, $^\dagger p < 0.01$ vs unaffected side.

adduction and internal and external rotation. Similar to the findings of Zorowitz [13], expansion of the range of shoulder external rotation in the early stage of stroke was seen in the present study. The increase in extension PROM in the affected shoulder may be due to the loss of shoulder flexor activity, since eccentric contraction of the flexor muscles is a brake for shoulder movement in extension [20].

There was no difference in PROM in elbow flexion and extension between the unaffected and affected sides. This may have been because the coronoid process of the ulna limits elbow flexion in the terminal range of motion [20, 21]. In elbow extension, it is likely that the olecranon process of the ulna terminates elbow extension [21]. The elbow joint is considered a stable joint, with structural integrity and good ligament and muscular support [20, 21]. Our results indicate that there is no influence of muscle tone on elbow PROM in flaccid hemiplegia patients.

A decrease in muscle tone affects wrist flexion and extension. In flaccid paralysis muscle, there is decreased stretch reflex excitability [1]. The increase in PROM is probably due to the lack of a negative feedback loop in the stretch reflex arc. During passive wrist flexion, there is no activity in the Ia afferent of wrist extensors, leading to no contraction of the wrist extensors and no inhibition of the wrist flexors, and vice versa for passive wrist extension. Thus, during measurement of PROM in wrist flexion, the wrist extensors can be extended considerable distances. Similarly, during measurement of PROM in wrist extension, the wrist flexors can be stretched until the termination of the wrist close-packed position. In radial and ulnar deviation, the movement occurs in the intercarpal joint that contributes little to wrist motion [20, 21]. Wrist radial and ulnar deviations result from the proximal row glides on the distal row of the carpal bone [21]. Decreased muscle tone had no influence on wrist deviations, possibly because of the limitation of the gliding between the proximal and distal row of the carpal bones.

There was a significant difference in PROM in hip abduction, adduction and external rotation, but not in hip flexion, extension or internal rotation, between the sound and affected sides. The hip joint is strengthened anteriorly and posteriorly with large strong ligaments [23, 24]. Thus, a difference in hip flexion and extension PROM between the unaffected and affected sides may not be observed. The increase in hip abduction, adduction and external rotation may be due to the ease with which the femur can be moved sideways in the frontal plane and rotated round the longitudinal axis. In the affected hip, the internal rotation PROM tended to increase, although not significantly, when compared with the unaffected hip. Hip ligaments resist internal rotation more than external rotation. In addition, a number of muscles contribute to hip external rotation more than hip internal rotation [23, 25]. Thus, passive hip internal rotation seems to be restricted by ligaments and hip external rotators.

Decreased muscle tone did not significantly affect PROM in knee flexion and extension. Normally, in flexion, the stability of the knee is derived from the powerful capsule, ligaments and muscle surrounding the joint. In extension, the knee is firm because of its alignment, the congruency of the joint and the effect of gravity [21]. However, knee hyperextension has been reported in spastic paretic stiff-legged gait [26]. In the present study, PROM was measured before subjects stood, walked, or were trained in weight-bearing on the affected leg. Thus, flaccid muscles may have no influence on PROM in knee flexion and extension in flaccid hemiplegia patients who do not put weight on the knee.

Ankle muscle tone did not influence ankle PROM. However, PROM in ankle plantarflexion was increased in the affected side compared to the sound joint. The increase probably resulted from the gravitational force influencing ankle plantarflexion when supine. The average number of days from stroke onset to PROM measurement in our subjects was 8.3 days, and a footboard was not provided to prevent foot drop while supine. Thus, subjects' affected ankles were always in plantarflexion, presumably leading to gain in length of ankle dorsiflexors, which in turn induced shortening in ankle plantarflexors. It could be suggested that a footboard should be used for flaccid hemiplegia patients as soon as they are admitted to the ward. Decreased muscle tone also did not influence ankle PROM in eversion and inversion. The possible reason is that ankle eversion and inversion occurs at the subtalar or talocalcaneal joint, in which the ligaments supporting the talus limit subtalar joint motion [25].

Conclusion

A decrease in muscle tone mainly causes an increase in PROM. In flaccid hemiplegia, increases in PROM were particularly shown in shoulder extension, shoulder adduction, shoulder internal and external rotation, wrist flexion and extension, hip abduction, hip adduction, hip external rotation and ankle plantarflexion. It is suggested that PROM maintenance in patients with flaccid paralysis should be performed carefully to avoid excessive motion range. In addition, a footboard to prevent foot drop should be used in flaccid paralysis stroke patients. We postulate that the flaccid paralysis muscle is a source of increased joint range of motion, particularly in flaccid hemiplegia.

References

1. Purves D, Augustine GJ, Fitzpatrick D, et al. Spinal circuit and motor control. In: Purves D, Augustine GJ, Fitzpatrick D, et al, eds. *Neuroscience*. Sunderland, MA: Sinauer Associates, 1997; 291–309.
2. Kandel ER, Schwartz JH, Jessell TM. Movement. In: Kandel ER, Schwartz JH, Jessell TM, eds. *Principles of Neural Science*, 4th edition. New York: McGraw-Hill, 2000;653–867.
3. Porter LL. Motor 2: higher centers. In: Cohen H, ed. *Neuroscience for Rehabilitation*, 2nd edition. Philadelphia: Lippincott Williams & Wilkins, 1999;243–75.
4. Yanagisawa N. Historical review of research on functions of basal ganglia. *Eur Neurol* 1996;36(Suppl 1):2–8.
5. Chaco J, Wolf E. Subluxation of the glenohumeral joint in hemiplegia. *Am J Phys Med* 1971;50:139–43.
6. Miglietta O, Lewitan A, Rogoff JB. Subluxation of the shoulder in hemiplegic patients. *NY State J Med* 1959;59:457–60.
7. Najenson T, Pikielny SS. Malalignment of the gleno-humeral joint following hemiplegia. A review of 500 cases. *Ann Phys Med* 1965;8:96–9.
8. Hakuno A, Sashika H, Ohkawa T, Itoh R. Anthrographic findings in hemiplegia shoulder. *Arch Phys Med Rehabil* 1984; 65:706–11.
9. Fitzgerald-Finch OP, Gibson II. Subluxation of the shoulder in hemiplegia. *Age Ageing* 1975:4;16–8.
10. Smith RG, Cruikshank JG, Dunbar S, Akhtar AJ. Malalignment of the shoulder after stroke. *Br Med J (Clin Res Ed)* 1982;284: 1224–6.
11. Cailliet R. *Shoulder Pain*, 2nd edition. Philadelphia: FA Davis, 1981;140–7.
12. Basmajian JV, Bazant FJ. Factors preventing downward dislocation of the abducted shoulder joint. *J Bone Joint Surg* 1959;41A:1183–6.
13. Zorowitz RD. Recovery patterns of shoulder subluxation after stroke: a six-month follow-up study. *Top Stroke Rehabil* 2001; 8:1–9.
14. Suzuki N, Ando M, Gotoh E. Hip joint instability in an infant with paraplegia following aortic surgery. *Paraplegia* 1990;28: 406–9.
15. McGrory BJ, Burke DW, Moran SJ. Posterior instability of the hip in an adult. A case report. *Clin Orthop* 1997;341:151–4.
16. Pandyan AD, Johnson GR, Price CI, et al. A review of the properties and limitations of the Ashworth and modified Ashworth Scales as measures of spasticity. *Clin Rehabil* 1999; 13:373–83.
17. O'Sullivan SB. Motor control assessment. In: O'Sullivan SB, Schmitz TJ, eds. *Physical Rehabilitation Assessment and Treatment*, 3rd edition. Philadelphia: FA Davis, 1994;111–31.
18. Reese NB, Bandy WD. *Joint Range of Motion and Muscle Length Testing*. Philadelphia: WB Saunders, 2002.
19. O'Sullivan SB. Stroke. In: O'Sullivan SB, Schmitz TJ, eds. *Physical Rehabilitation Assessment and Treatment*, 3rd edition. Philadelphia: FA Davis, 1994;327–60.
20. Hall SJ. The biomechanics of the human upper extremity. In: Hall SJ, ed. *Human Biomechanics*, 4th edition. New York: McGraw-Hill, 2003;183–227.
21. Hamill J, Knutzen KM. Functional anatomy of the upper extremity. In: Hamill J, Knutzen KM, eds. *Biomechanical Basis of Human Movement*, 2nd edition. Philadelphia: Lippincott Williams & Wilkins, 2003;129–69.
22. Saha AK. Dynamic stability of the glenohumeral joint. *Acta Orthop Scand* 1971;42:491–505.
23. Hall SJ. The biomechanics of the human lower extremity. In: Hall SJ, ed. *Human Biomechanics*, 4th edition. New York: McGraw-Hill, 2003;228–74.
24. Luttgens K, Deutsch H, Hamilton N. The lower extremity: the knee, ankle, and foot. In: Luttgens K, Deutsch H, Hamilton N, eds. *Kinesiology Scientific Basis of Human Motion*, 8th edition. Dubuque: William C Brown Communications, 1992;210–41.
25. Hamill J, Knutzen KM. Functional anatomy of the lower extremity. In: Hamill J, Knutzen KM, eds. *Biomechanical Basis of Human Movement*, 2nd edition. Philadelphia: Lippincott Williams & Wilkins, 2003;171–232.
26. Adams JM, Perry J. Gait analysis: clinical application. In: Rose J, Gamble JG, eds. *Human Walking*, 2nd edition. Philadelphia: Lippincott Williams & Wilkins, 1994:149.